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Energy and protection of the atmosphere

Report of the Secretary-General

SUMMARY

The extraction, conversion and combustion of fossil fuels and, to a lesser degree, changes in land-use and agriculture have led to increasing concentrations of greenhouse gases. This interference could possibly lead to climate change.

Protection of the atmosphere is an important precondition for ensuring sustainable economic development. Energy needs are determined by three principal factors: population growth, economic and industrial development, and technological change. The type and the extent of the environmental impact of energy production and use are closely related to the degree of economic development and industrialization. Three classes of economic problem have been studied in relation to the environment - problems associated with poverty, industrialization and affluence. Each places a different burden on the environment.

Global primary energy use has increased by a factor of 20 since the middle of the past century. There is, however, considerable variation in the growth rates of energy consumption over time between different world regions. Much of the increase in global primary energy consumption has occurred in the developed countries. Energy intensities tend to decrease as levels of economic and technological activity increase.

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Developed countries account for most of the carbon dioxide, aerosol and chlorofluorocarbon emissions. At present, it is not possible to determine reliably the combined effects of the concentration of greenhouse gases and of human activities on the climate system. Because of the difficulty in establishing the likely magnitude and geographical distribution of climate change, it is very difficult to determine what levels of human interference should be considered dangerous.

A range of options to mitigate against undesirable impacts on the atmosphere is available. The technical options include efficiency improvements, fuel switching, structural change, control of large point sources, enhancement of greenhouse gas sinks and adaptation measures. A variety of policy options is also available.

CONTENTS

	Paragraphs	Page
INTRODUCTION	1	5
I. BACKGROUND	2 - 10	5
A. Local and transboundary air pollution	4	5
B. Greenhouse gases and climate change	5 - 7	6
C. Energy for development	8 - 10	6
II. THE ROLE OF ENERGY IN ECONOMIC DEVELOPMENT	11 - 22	7
A. Energy supply and consumption, by region	12 - 17	7
B. Economic development in relation to the environment	18 - 22	11
III. TRENDS IN ENERGY USE	23 - 37	12
A. Sectoral and regional patterns	26 - 28	12
B. Energy intensities	29 - 33	13
C. Atmospheric concentrations of carbon dioxide	34 - 37	14
IV. THE ATMOSPHERIC IMPACT OF GREENHOUSE GASES	38 - 47	15
A. Scientific understanding of climate change	38 - 44	15
B. Range of future emissions	45 - 47	17
V. TECHNICAL OPTIONS FOR MITIGATION AND ADAPTATION	48 - 70	17
A. Improving efficiency	50 - 57	18
B. Fuel switching and substitution	58 - 59	19
C. Structural change	60 - 61	20
D. Control of large point sources	62 - 64	20
E. Enhancement of natural sinks	65 - 67	21
F. Adaptation measures	68 - 70	22
VI. SPECIAL CIRCUMSTANCES IN DIFFERENT REGIONS	71 - 77	23

CONTENTS (continued)

		Paragraphs	Page
VII.	POLICY OPTIONS FOR CONTROLLING ANTHROPOGENIC IMPACTS ..	78 - 100	24
	A. Policies for sustainable energy development	79 - 80	24
	B. Policies for energy efficiency and decarbonization	81 - 82	25
	C. Market and non-market instruments	83 - 87	25
	D. Regional and national instruments	88 - 89	26
	E. Adequate financing	90 - 91	26
	F. Enhancing knowledge and skills	92 - 93	27
	G. Sector-specific and technology-specific policy instruments	94 - 100	27

Figures

I. PRIMARY ENERGY USE IN 1990, BY SOURCE, COMPARED TO POPULATION, BY REGION 8

II. PRIMARY ENERGY USE VERSUS GDP PER CAPITA FOR SELECTED REGIONS AND TWO HISTORICAL TRAJECTORIES, FOR THE UNITED STATES (1800-1990) AND JAPAN (1900-1990) 10

INTRODUCTION

1. The Committee on New and Renewable Sources of Energy and on Energy for Development at its first session (7-18 February 1994) requested the Secretary-General to prepare a report on energy and protection of the atmosphere for consideration by the Committee at its second session. 1/ This report has been prepared in response to the Committee's request. It is based almost exclusively on a study commissioned by the Secretariat. 2/

I. BACKGROUND

2. The earth's atmosphere is affected by many interrelated sources of interference. They include local and regional air pollution and increasing concentrations of greenhouse gases, aerosols, and halocarbons. Combustion of fossil fuels and unsustainable uses of biomass fuels cause extensive local and regional air pollution, often resulting in acidification which damages entire ecosystems. The extraction, conversion and combustion of fossil fuels and, to a lesser degree, changes in land-use and agriculture lead to increasing concentrations of greenhouse gases, which are altering the radiative balance of the atmosphere, possibly causing climate change. Human activities have increased the atmospheric concentrations of many naturally occurring gases and have also added new ones. Anthropogenic sources of chlorofluorocarbons are adding to the greenhouse effect and are gradually destroying the ozone layer. Taken together, these human activities are projected to change regional and global climate. The changes will affect large populations, especially the more vulnerable ones, with fewer abilities and resources to adapt.

3. Protection of the atmosphere is an important precondition for ensuring that economic development can proceed in a sustainable manner. This report addresses issues concerning the protection of the atmosphere from energy-related sources of human interference. It analyses the relationship between energy and development, prevailing trends in energy use throughout the world and possible future developments, possible impacts on the atmosphere, and strategies for mitigating and adapting to the adverse impact of possible climate change. The report concludes with a discussion of policy measures for the protection of the atmosphere within the context of sustainable human development.

A. Local and transboundary air pollution

4. Local and transboundary pollutants from energy-related activities cause air quality to deteriorate in many urban and some rural regions throughout the world. They also cause economic and health damage and endanger ecosystems. High levels of indoor air pollution from burning low-quality biomass or coal in traditional open fireplaces are widespread in developing countries. Sulphur dioxide and nitrogen oxide emissions from fossil-fuel power plants and dense motorized traffic cause regional and transboundary air pollution which leads to the acidification of forests, lakes and soils. "Acid rain" has been a particular problem in Europe and North America. More recently, transboundary

air pollution and increasing acidification have also become sources of concern in the rapidly developing, coal-intensive economies of East Asia.

B. Greenhouse gases and climate change

5. Concentrations of greenhouse gases have increased significantly since the beginning of the fossil-fuel era, two centuries ago. Atmospheric concentrations of carbon dioxide have increased by 30 per cent, those of methane by 150 per cent, and those of nitrous oxides by over 10 per cent. Scientific evidence is strong that most of these increases are due to human activities such as the burning of fossil fuels, changes in land-use, and agriculture. Increasing concentrations of greenhouse gases tend to warm the atmosphere, whereas aerosol emissions such as sulphur dioxide tend to cool it in some regions.

6. The increases in atmospheric greenhouse gases and aerosols, taken together, are expected to lead to higher mean global temperatures and are projected to change regional and global climate, including, inter alia, precipitation, soil moisture, air and ocean currents, and sea levels. Climate change, in turn, could lead to adverse environmental impacts, affecting human activities and endangering sustainable development. The exact nature of these impacts, including their extent, variability and regional patterns, is subject to considerable scientific uncertainty.

7. The depletion of the stratospheric ozone layer is largely caused by emissions of chlorofluorocarbons and halons, which result in increased ultraviolet radiation reaching the earth's surface. This affects human health, causing increased cases of skin cancer and eye disease. The chlorofluorocarbons also produce a greenhouse effect; however, it is offset somewhat by decreases in ozone, which is also a greenhouse gas. A reduction in ozone-depleting substances is regulated by the Montreal Protocol on Substances that Deplete the Ozone Layer, 3/ but some of the replacements for ozone-depleting substances are, in their turn, potent greenhouse gases.

C. Energy for development

8. Despite tremendous increases in commercial energy use, to date, the majority of the global population still has inadequate access to the kind of energy services enjoyed by the inhabitants of the industrialized countries. A lack of adequate energy services is one of the symptoms of poverty. The inequalities are so large that it would be virtually impossible for the majority of the world's population to enjoy resource-intensive energy-use patterns similar to those prevailing in the industrialized countries. More sustainable energy patterns throughout the world and the protection of the atmosphere are recognized as important policy objectives at both the national and international levels. International environmental agreements are being extended from the local and national to international levels.

9. Adequate protection of the earth's atmosphere involves a number of formidable challenges. Considerable increases in energy are required to satisfy

basic human needs and to further social and economic development. However, the current, largely inadequate, use of energy in many instances already produces emissions that exceed tolerable levels in urban regions and that exceed the critical loads for many ecosystems in rural regions. Remedies are needed urgently, but the current dependence on fossil fuels for the provision of energy services will persist for many decades. Establishing more sustainable energy-use patterns would require considerable research and development (R&D) efforts and determined policy measures. It would be very capital-intensive, requiring new forms of financing and many decades of capital turnover.

10. Protection of the atmosphere at the local, regional, and global levels faces a number of competing social and economic policy concerns. Some of them have higher priorities, such as the eradication of poverty, provision of adequate health care and employment opportunities. The challenge of protecting the atmosphere is further compounded by persistent scientific uncertainties concerning the exact nature of the interaction between human activities and the atmosphere and about the possible impacts of climate change, including the costs and benefits of adaptation and mitigation.

II. THE ROLE OF ENERGY IN ECONOMIC DEVELOPMENT

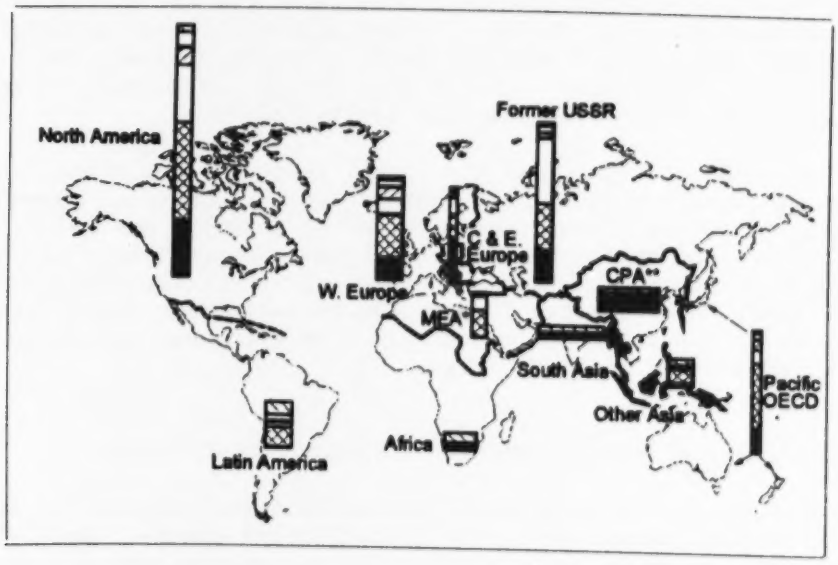
11. Energy needs are driven by three principal factors: population growth, economic and industrial development, and technological change. Energy can be seen as one of the fundamental requirements for economic growth and social improvements, and not just a consequence of such growth.

A. Energy supply and consumption, by region

12. To provide the required energy services, in the form of heat, light and work, prior to the Industrial Revolution, the energy system relied on harnessing natural energy flows and on animate and human power. Power densities and availability were constrained by site-specific factors. Mechanical energy sources were limited to draught animals, water and windmills. Burning of fuelwood and tallow candles were the only means of converting chemical energy to heat and light. Energy consumption typically did not exceed 0.5 tons of oil equivalent (toe) per capita per year. 4/ Today, some 2 billion people still rely on similar traditional energy end-use patterns. They use traditional energy forms and technologies and have no access or inadequate access to modern energy services. This severely constrains the satisfaction of basic needs, precludes the modernization of economic structures and hinders human development.

13. Figure 1 shows the 1990 per capita energy consumption in a number of regions, by source, and contrasts it with their respective populations. The height of the bars in the figure is proportional to current per capita energy use; the width of the bars is proportional to population size. Hence, the area of each bar is proportional to total energy use. The differences in the per capita primary energy consumption in the world are indeed very large. Less than a third of the world's population consumes more than two thirds of the

Figure I. Primary energy use in 1990, by source, compared to population by region



Key: Height of bar = energy use (toe/capita)

Width of bar = population (millions)

* Middle East and North Africa

** Centrally planned Asia and China

Source: Department for Policy Coordination and Sustainable Development of the United Nations Secretariat.

global energy. Cumulative historical consumption is even more unevenly distributed: about 85 per cent of all energy used to date has been consumed by less than 20 per cent of all the people who have lived since 1860.

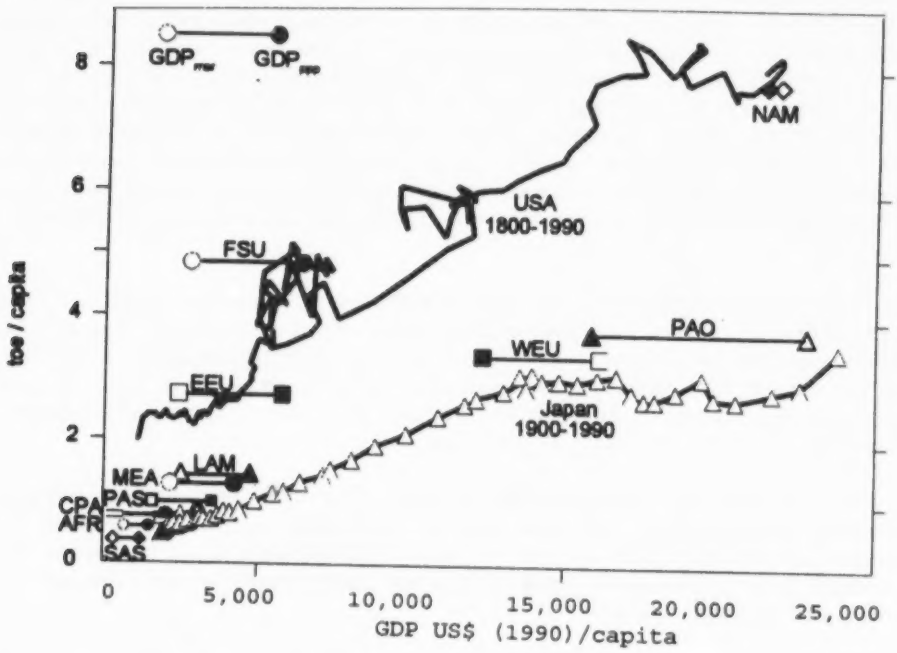
14. Current per capita commercial energy consumption varies by a factor of more than 20 between North America and South Asia. These disparities are even higher in the use of modern, commercial energy forms. Commercial energy use per capita can differ by as much as 500 times between individual countries, in the most extreme cases. Western Europe and Japan have much lower per capita energy consumption than North America, with about the same levels of affluence, indicating a substantial degree of diversity in energy consumption patterns even among the developed countries. Disparities are also large among developing countries, and they are even larger across different social and economic groups everywhere.

15. Another important difference is the structure of energy supply. Developing countries rely primarily on coal and other solid fuels, such as traditional and non-commercial sources of energy. 5/ Most of the developed countries draw on large shares of crude oil and natural gas in their primary energy consumption; some regions have substantial contributions of nuclear energy and modern renewable sources.

16. There is a visible and statistically significant relationship between per capita energy consumption and per capita economic output, measured in terms of gross domestic product (GDP), both at prevailing market exchange rates (mer) and at purchasing power parities (ppp), across individual countries and regions and over time (see figure II).

17. At one extreme are the low-income countries with lowest per capita energy use. They include sub-Saharan Africa and South Asia. As incomes rise, so does energy use. At intermediate levels of per capita economic output and energy use are the economies of North Africa and the Middle East, Pacific Asia and Latin America. Current per capita primary energy use in some of the higher income economies of Asia already exceeds that of some developed countries. 6/ Although this pattern of energy use growing with economic development is pervasive, there is no unique and universal "law" that specifies an exact relationship between the two.

Figure II. Primary energy use versus GDP per capita for selected regions and two historical trajectories, for the United States (1800-1990) and Japan (1900-1990)



Key:

SAS	South Asia	EEU	European Community
AFR	Africa	FSU	Former Soviet Union
CPA	Centrally planned Asia	WEU	Western Europe
PAS	Pacific Asia	USA	United States of America
MEA	Middle East	PAO	Pacific/Asia Oceania
LAM	Latin America		
NAM	North America		

Source: Department for Policy Coordination and Sustainable Development of the United Nations Secretariat.

Notes: 1990 United States dollars at market exchange rates and purchasing power parities.

B. Economic development in relation to the environment

18. The type and the extent of the environmental impacts of energy production and use are closely related to the degree of economic development and industrialization. Three different classes of economic problem have been analysed in relation to the environment: problems of poverty, industrialization, and affluence. 7/ Different stages of economic development place different burdens on the environment. But economic development also enables societies to resolve environmental challenges. Different types of economic problems call for different environmental policy approaches and solutions.

19. Environmental problems that result from poverty include inadequate sanitation, lack of clean drinking water, high levels of indoor and outdoor particulate matter and air pollution. The impacts are usually felt in only those areas close to the source of pollution. They often include poor human health, sometimes resulting in high mortality. The most effective policy response to these types of environmental problems is economic development itself.

20. Environmental problems related to the process of industrialization include high ambient concentrations of sulphur dioxide and high levels of hazardous industrial wastes. Problems emerge primarily in urban and industrial areas, but with increasing levels of industrialization, they also spread to larger regions and start affecting many ecosystems in addition to human health. The environmental impacts can last days (urban smog) or much longer, as in cases of regional-scale pollution like acid rain, toxification of river basins, or deforestation of whole regions. The environmental problems associated with industrialization tend first to intensify and increase in magnitude and extent, reach a peak, and thereafter decline. The increase is due to the expansion of production and urbanization. The decline is related to economic development. The policy measures required to resolve the environmental problems of industrialization need to combine incentives for a cleaner environment with regulatory mechanisms. Incentives should foster structural change towards more efficient use of energy and other resources, including better energy end-use devices, cleaner fuels and improved public infrastructures, among others. Regulatory mechanisms should, inter alia, include environmental standards, financial and tax incentives, control of large point sources, and regular equipment maintenance and replacement.

21. Typical examples of environmental problems associated with affluence include ever increasing volumes of municipal waste and energy-related emissions of greenhouse gases, most notably carbon dioxide (CO_2). The environmental impacts are mostly of an indirect, long-term nature. Their extent and exact nature are often uncertain. Examples include climate change and loss of biodiversity. In contrast to the environmental problems associated with the first two categories, those associated with affluence and rising levels of income and consumption tend to become exacerbated. Hence, policy strategies need to be comprehensive and cover numerous economic activities, and they need to promote long-term structural changes for production and consumption alike. There are generally no easy, quick "technological fixes".

22. Two important generic strategies to address environmental issues at high levels of income and consumption are improved energy efficiency and "decarbonization" of energy - that is, changes that produce cleaner fuel supply and end-use structures.

III. TRENDS IN ENERGY USE

23. Global primary energy use has increased by a factor of 20 since the middle of the nineteenth century: an average annual growth rate of 2.2 per cent per year. Global primary energy use, including traditional fuels, amounted around 1860 to less than 0.5 gigatons oil equivalent (Gtoe). By the turn of the century, global primary energy use had more than doubled; it doubled again by the 1940s. The next two doublings took only about 20 years each. In 1994 global primary energy use amounted to 9.1 Gtoe. 8/

24. The mix of primary energy sources has also changed dramatically in the last century. The evolution of the relative shares of each of the most important sources of energy in total global consumption, the dynamics of structural change in the global energy system, and the relative shares of different primary energy sources in global primary energy show that it took about half a century before coal was replaced by crude oil as the dominant global energy source. At the global level, the time constant for fundamental energy transitions has been on the order of 50 years. At the regional level and for individual energy technologies and devices, the characteristic time constants are usually shorter, as a result of faster capital turnover, among other factors.

25. In the energy sector the lifetime of energy equipment, and hence the turnover and capital stock replacement rate, is generally shorter, the closer the equipment is to the end-user. Typical end-use devices such as light bulbs are usually replaced within one year; household devices, within ten years; and residential capital equipment, within 20 years. The lifetimes of energy facilities, however, are much longer: fossil power plants and renewable energy projects last about 30 years. Yet longer useful lives are observed for large hydro-schemes (dams) and for infrastructure (railway lines, roads, underground cables). The representative lifetime of energy facilities of 30-50 years implies that the totality of the energy-sector capital stock will be replaced at least twice before the end of the twenty-first century, offering numerous opportunities for improvements in efficiency, and for restructuring the energy system away from fossil fuels.

A. Sectoral and regional patterns

26. Sectoral energy-use patterns vary considerably in different world regions and countries. Of the 9 Gtoe of primary energy consumed worldwide in 1990, about 6.5 Gtoe were delivered to final use, implying an overall primary-to-final energy conversion efficiency of about 72 per cent. The 6.5 Gtoe of final energy is divided unequally among sectors. The largest share (about 40 per cent) is for combined energy use in agriculture, households and commercial sectors, including the direct use of traditional, non-commercial fuels collected and consumed locally. The next largest share (about 31 per cent) is accounted for

by industrial energy uses, and another 6 per cent, by industrial feedstock requirements (non-energy uses of fossil fuels). Globally, the transport sector has the lowest share (about 23 per cent) in all final energy use, but the highest growth rate of all sectoral energy uses.

27. In the OECD countries, final energy consumption is almost equally distributed among the sectoral uses. In the economies in transition, industrial uses account for by far the largest share; in developing countries, agricultural, household and commercial activities account for the largest share. In both the OECD and developing countries, the highest rates of growth are found in transportation energy requirements. Industrial energy use has actually decreased in the OECD countries. By contrast, industrial energy use is growing rapidly in developing countries due to economic development and industrialization.

28. Much of the increase in global primary energy consumption has occurred in the developed countries. While they still consume two thirds of all primary energy, their share is declining as the world develops. Energy consumption is growing especially rapidly in certain economies in Asia, and most of the increases in future energy consumption are expected to occur in what are now developing countries. Most of the historical and current energy consumption is accounted for by the industrialized regions of the world. During most of the current century, the growth rates of energy consumption in the developing economies exceeded those in the industrialized countries by a wide margin, albeit at substantially lower absolute consumption levels. Especially high are the growth rates of fossil fuel energy consumption in the developing countries, in particular during the 1950s and 1960s, averaging almost 9 per cent per year. This illustrates the rapid replacement of traditional energy forms by commercial (fossil) forms in addition to and beyond the increase in energy consumption and economic development in those regions. Although the growth rates have slowed down over the past decade, the process continues.

B. Energy intensities

29. Economic development and technological change also affect energy intensities - that is, the amount of energy required per unit of economic output, usually measured by gross domestic product (GDP), either for the economy at large or for particular sectors/activities. The causes of decreases in energy intensities are many and complex. They include technological improvements in individual energy end-use and conversion components; structural shifts in the energy system, such as moving from coal-fired electricity generation to a gas-fired combined cycle plant; and interfuel substitution at the level of energy end-use, like the replacement of fuelwood by liquid petroleum gas (LPG). They also include economic shifts from more to less energy-intensive activities, changing patterns of energy end-uses, and ultimately, changing lifestyles. Not every change in every one of these categories represents a decrease in energy intensity. But taken together, the overall trends are persistent and pervasive.

30. Aggregate energy intensities, including non-commercial energy, generally improve over time, and this is true in all countries. The process is not always

smooth. Periods of rapid improvement are interlaced with periods of stagnation. Energy intensities may even rise in the early takeoff stages of industrialization, when an energy-intensive and materials-intensive industrial and infrastructure base needs to be developed.

31. While aggregate energy intensities generally improve over time, commercial energy intensities follow a different path. They first increase, reach a maximum, and then decrease. The initial increase is due to commercial energy carriers substituting for traditional energy forms and technologies. Once that process is largely complete, commercial energy intensities decrease in line with the pattern found for aggregate energy intensities.

32. While the trend is one of conditional convergence across countries, the patterns of energy intensity improvements in different countries reflect their different situations and developmental histories. Economic development is a cumulative process, incorporating in different countries different consumption lifestyles, different settlement patterns and transport requirements, different industrial structures, and different takeoff dates into industrialization. Thus the evolution of national energy intensities is path dependent.

33. Five countries illustrate the different national experiences in energy and carbon intensities. The United States of America has one of the highest energy intensities of the industrialized countries and accounts for one of the highest per capita carbon emissions in the world. France and Japan, on the other hand, have among the lowest carbon intensities, but for different reasons: in Japan, by substituting oil and natural gas for coal, and in France, by substituting nuclear energy for fossil fuels. Finally, China and India, two rapidly developing countries, are in the process of replacing traditional energy by fossil energy, resulting in very high energy and carbon intensities. Together, these five countries account for almost half of global energy consumption and energy-related carbon dioxide emissions.

C. Atmospheric concentrations of carbon dioxide

34. The legacy of the tremendous expansion in the use of predominantly fossil fuels has become apparent. Since the onset of the Industrial Revolution, the atmospheric concentration of carbon dioxide has increased from 280 ppm (part per million by volume) to over 358 ppm.

35. The industrialized countries account for most (some 60 per cent) of the present carbon dioxide emissions. However, the emissions of developing countries are growing more rapidly than those of the industrialized ones, although at much lower absolute levels. From 1850 to date, some 240 gigatons of elemental carbon (GtC) have been released into the atmosphere in energy-related activities. This is much larger than the estimated carbon release - some 120 GtC - from deforestation and land-use changes over the same period.

36. The significant gap between developed and developing countries in current fossil energy carbon emissions becomes even larger when the historical dimension is considered: because of the long lifetime of atmospheric carbon, estimates indicate that about 84 per cent of the fossil energy carbon dioxide still

remaining in the atmosphere since 1800 can be attributed to emissions from the now industrialized countries. The share of developing countries (16 per cent) is very low, especially in view of the fact that about 70 per cent of the earth's population since 1800 reside(d) in those countries. The significant difference in historical contributions of CO_2 is somewhat reduced when all sources and species of greenhouse gases are analysed.

37. Currently the largest single source of fossil fuel carbon emissions is coal, with about 43 per cent share, followed by oil, with about 39 per cent, and natural gas, with 18 per cent. Adding non-energy uses of fossil fuels, such as industrial feedstocks, reverses the shares to 40 per cent for coal and 42 per cent for oil.

IV. THE ATMOSPHERIC IMPACT OF GREENHOUSE GASES

A. Scientific understanding of climate change

38. Atmospheric trace gases help to regulate the temperature regime of the earth. Radiation from the sun is the source of energy which drives the climate system. Incoming solar radiation warms the surface of the earth. Much of this energy is in the visible part of the electromagnetic spectrum. To balance the incoming energy from the sun, the earth itself must radiate on average the same amount of energy back to space by emitting in the infrared part of the spectrum. Part of the re-emitted radiant heat is trapped by trace gases in the atmosphere, producing the "greenhouse effect". Most of the atmosphere consists of nitrogen and oxygen, which are both transparent to infrared radiation. The most important infrared absorbing atmospheric gases are water vapour and carbon dioxide, which account for 90 per cent of the natural greenhouse effect. Other greenhouse gases include methane, nitrous oxide, and tropospheric ozone.

39. Since the onset of the Industrial Revolution human activities have not only increased the atmospheric concentrations of naturally occurring greenhouse gases but have also added new ones. The anthropogenic sources of chlorofluorocarbons (CFCs) also produce a greenhouse effect, although this has been offset somewhat by the observed decrease in lower stratospheric ozone since the 1970s, caused principally by CFCs and halons. Human activity has altered the concentration of greenhouse gases both directly by anthropogenic emissions of carbon dioxide, methane, nitrous oxide and CFCs, and indirectly by influencing the complex atmospheric chemistry, including increased concentrations of stratospheric water vapour and tropospheric ozone, and the depletion of stratospheric ozone.

40. Human activity also affects the quantity of aerosols in the atmosphere, which influence climate in other ways. They scatter some of the incoming solar radiation back to space and thereby cool the earth's surface. Many of them also act as nuclei on which cloud droplets condensate and hence alter the absorption of solar radiation by the clouds. Aerosols occur naturally in the atmosphere - e.g., from the eruption of volcanos or by being blown off the surface of deserts. Sulphur dioxide from coal power plants and the burning of biomass is the main aerosol resulting from human activity. Previously it was thought to affect only local smog and regional acidic precipitation, but recent IPCC findings indicate that some of the net climate warming resulting from the

increased concentrations of greenhouse gases is being partially offset by increased concentrations of sulphur dioxide. However, the aerosol effects do not cancel the global-scale effects of the much longer lived greenhouse gases, and significant climate change may still result, especially once aerosol emissions are effectively controlled to combat local and regional air pollution.

41. An analysis of surface temperatures indicates that there has been a global mean warming of 0.3-0.6 degrees Kelvin over the past 100 years. The observed trend of a larger increase in minimum than in maximum temperatures is apparently linked to associated increases in low clouds and aerosols and to the enhanced greenhouse effect. In addition, the warmest seven years on observed record have occurred since the early 1980s. The past 15 years have on average probably been warmer than any similar period during the past 600 years. It is also known that the 240 GtC of carbon dioxide emitted due to the use of fossil fuels and the 120 GtC emitted due to deforestation and the burning of biomass have increased atmospheric carbon dioxide content by about 28 per cent, compared to pre-industrial concentration levels. The concentrations of other greenhouse gases such as methane, nitrous oxide and CFCs have also increased markedly. Their total combined effect (excluding that of water vapour) is at present equivalent to an increase in carbon dioxide of almost 50 per cent.

42. Unfortunately, it is not possible to determine reliably the combined effects of increasing concentrations of greenhouse gases and of human activity on the climate system. Theoretical models of the atmosphere have determined that the resulting increase in global mean temperature would be in the range of 0.8-2.2 degrees Kelvin. The inertia of the climate system compared to the comparatively fast rates of increase in the concentration of greenhouse gases reduces the increase by 30-50 per cent. In addition, the anthropogenic sources of aerosols (principally, sulphur dioxide) reduce the increase by 20-40 per cent. Thus, the observed climate change of 0.3-0.6 degrees Kelvin is at the lower end of what would be theoretically expected.

43. Because of the difficulty in predicting the magnitude and geographical distribution of climate change, a determination of what might be considered "dangerous" levels of anthropogenic interference with the climate system is primarily a policy rather than a scientific question. People have adapted with varying degrees of success to natural climate variability in the past. Since there is a large uncertainty about where, how quickly felt and how severe the adverse impacts of climate change might be and what might be their potential benefits, this analysis will focus on possible strategies to stabilize greenhouse concentrations at alternative levels.

44. Certain problems are posed by the goal to stabilize the concentrations of greenhouse gases. It is known that enhanced concentrations of such gases remain on average in the atmosphere for 50-100 years. (An exception is methane, with a lifetime of somewhat more than a decade.) This has two important implications for sustainable development. First, a significant decrease in greenhouse warming might take half a century or more, even after concentrations of greenhouse gases are stabilized. Secondly, the long time-scale of climate change and the atmospheric lifetimes of most greenhouse gases are almost matched by the long time-scales of replacing human infrastructures, such as the energy system. This implies a lag of many decades before stabilization of

concentrations is achieved and an equivalent lag before stabilization of temperature occurs.

B. Range of future emissions

45. The crucial scientific objective in the context of possible climate change is to design different emission scenarios that bracket a sufficiently wide range of alternative levels of concentration of atmospheric greenhouse gases. By doing so, one can explicitly specify the alternative energy development paths that correspond to different concentration levels and thus aid the policy process of identifying the level that would prevent dangerous interference with the climate system.

46. An analysis of alternative scenarios indicates that cumulative emissions over time are the single most important factor for determining the level of future greenhouse gas concentrations. This means that the shape of the emissions path is not that crucial as long as the total emissions are not changed by a given period. What is common to all of the paths that lead to stabilization is that their emissions must fall to 3 GtC or less per year by the time stabilization is achieved. This decrease corresponds to the capacity of natural sinks to absorb additional carbon dioxide emitted to the atmosphere.

47. An overall result of the analysis is that scenarios that lead to stabilization at levels of about 450 ppmv have cumulative emissions in the range of about 600 GtC by 2100. Scenarios with cumulative emissions of more than 1,000 GtC by 2100 result in concentrations of more than 550 ppmv, or more than double the pre-industrial levels. Scenarios in excess of 1,000 GtC cumulative emissions by 2100 lead to continuing increases in concentration levels beyond that period. In comparison, the current atmospheric carbon dioxide content is about 760 GtC. Therefore, sustainable energy development from the point of view of the current understanding of possible climate change implies cumulative carbon dioxide emissions by 2100 in the range of less than 1,000 GtC. Most of the scenarios that lead to emissions in this lower range involve active measures to change the structure of future energy systems so as to lead to lower environmental impacts with sufficient energy for economic development.

V. TECHNICAL OPTIONS FOR MITIGATION AND ADAPTATION

48. Mitigation and adaptation options need to be varied and comprehensive in view of the multitude of pollutants, the pervasiveness of emissions across a wide range of human activity, and especially the time-scales involved in possible climate change. The most obvious way to mitigate against the undesirable impacts of unabated emissions is to reduce emissions.

49. The overall emissions released by an energy system depend on the structure and efficiency of energy supply, conversion, and end-use. Emission reductions can be achieved by improvements in efficiency, fuel switching and structural change to cleaner forms of energy and by technological methods of reducing pollutants from large point sources. Two further mitigation options are the

enhancement of greenhouse gas sinks and adaptation measures. These are assessed below.

A. Improving efficiency

50. Efficiency improvement constitutes the most generic mitigation option. It reduces not only the amount of primary energy required but also the adverse environmental impact of all pollutants, resource use and energy costs. It is the option generally considered to have the largest mitigation potential. Whether energy is used efficiently depends on various technical factors but is more often a question of economic and social choice - i.e., a question of lifestyles and, consequently, the kinds of energy services that are demanded and provided.

51. At the turn of the century, the prevailing efficiency of electricity generation was about 5 per cent, whereas today the average efficiency in OECD countries is about 36 per cent, and the best combined-cycle natural gas-fired power plants can achieve more than 50 per cent efficiency. The average aggregate efficiency of energy conversion from primary to useful forms at the global level is about 34 per cent. The highest efficiencies are in the conversion of fuels from primary to secondary energy forms. Refinery efficiency is about 90 per cent, and, on average, the conversion, transport, and distribution of energy have rather low losses, with efficiencies ranging from about 60 to almost 90 per cent.

52. Overall, the processes of energy conversion from primary to final forms are quite efficient, with a global average of about 74 per cent. In comparison, conversion from final to useful forms, the domain of the energy consumers, is very inefficient, about 46 per cent at the global level. In general, natural gas and electricity have the highest end-use efficiencies compared with the lowest primary-to-final conversion rates. The lowest end-use efficiencies are those of biomass, with about 17 per cent, mainly as a result of the predominance of traditional end-use conversion devices in developing countries. Overall primary-to-useful energy efficiencies are 34 per cent at the global level. Corresponding numbers for different regions are 22 per cent in the developing countries and 42 per cent in the economies in transition. The most important overall conclusion is that energy end-use is the least efficient part of all energy systems, and it is in this area that improvements would bring the greatest benefit. Even the most efficient technologies may not be able to offset the energy-intensive lifestyles prevailing in very affluent market economies.

53. The greatest relative potential for improving efficiency exists in the developing countries, followed by the transitional economies, because of the prevalence of traditional economic patterns and inefficient energy end-use technologies in those areas. Outdated technological vintages and, more generally, chronic capital shortages limit the replacement of obsolete technologies and investment by new, more energy-efficient ones. The greatest absolute potential remains in the industrialized countries of the OECD, despite their generally more modern and energy-efficient capital stock.

54. Improved efficiency generally reduces resource use and the environmental impact of all pollutants, across all spatial and temporal scales. Decarbonization also entails elements of multipurpose strategies, since it can simultaneously reduce global, regional and local energy-related pollution. In addition to improvements in efficiency and cleaner energy, so-called "end-of-the-pipe" pollution abatement systems have been successfully applied to large point sources and more recently to some mobile sources. These include sulphur and nitrogen scrubbers for power plants and catalytic converters for motor vehicles.

55. An appropriate way to measure energy improvement potential is to determine the theoretical minimum energy requirements for a given task, as defined by the second law of thermodynamics (so-called exergy analysis). Such analysis provides useful insights for identifying those areas that have the greatest efficiency improvement potentials. For fossil energy uses, they are also the areas with the greatest emission reduction potentials.

56. A number of studies based on exergy analysis indicate that primary-to-service efficiencies are as low as a few per cent. The overall primary-to-service efficiency for the United States is 2.5 per cent. 9/ Other estimates for individual countries range up to 15-23 per cent. 10/ Estimates of global and regional primary-to-service exergy efficiencies vary from 10 to as low as a few per cent. 11/

57. These results indicate that the theoretical potentials for efficiency improvements are very great, ranging from a factor of 5 to 20. The actual realization of these potentials depends on numerous factors and constraints - among others, technology development, transfer and diffusion, capital availability and appropriate economic and institutional incentives, including removal of barriers and distortionary subsidies. It presupposes, moreover, the availability of financing and the existence of the appropriate incentives.

B. Fuel switching and substitution

58. Fuel switching, which involves structural shifts from emission-intensive fossil fuels to cleaner ones has a considerable emission reduction potential. For instance, switching from coal to natural gas reduces the emission of carbon dioxide particulates and sulphur dioxide, which constitute important local and regional air pollutants. The ultimate potential of emission reduction via fuel substitution is difficult to determine. Regional resource availability, trade possibilities, price differentials and geopolitical considerations may limit fuel substitution possibilities. The near-term potential of fuel substitution is rather limited, because the development of alternative energy supply sources, conversion facilities and end-use devices and the corresponding changes in infrastructures all take considerable time.

59. Over longer time periods, the emission reduction potentials increase substantially. By the end of the twenty-first century, according to a scenario relying on natural gas as a transitional fuel in conjunction with significant market penetration of cost-effective nuclear and renewable energy sources, carbon emissions might amount to only about 7 GtC, compared to 22 GtC for a

similar but coal and synfuel-intensive scenario. For both scenarios, global energy demand is projected to be five times higher than it is today. The investments embodied in existing energy infrastructures and regional resource availabilities constrain the emissions reduction potentials of fuel substitution. In view of such constraints, this option would be more effective if it were combined with vigorous efficiency improvement efforts and ultimately with carbon scrubbing and disposal.

C. Structural change

60. Structural change involves transformation of the energy system. The fossil fuels which currently predominate would be displaced by carbon-free energy sources, such as solar and nuclear, or by sources that are carbon-neutral with respect to the atmosphere, such as biomass. The emissions reduction potential of carbon-free and carbon-neutral energy sources is large indeed and in the long run may exceed that of efficiency improvements. Studies indicate that over very long time scales, it would be possible to restructure the global energy system entirely, away from the use of fossil fuels, especially when vigorous conservation and energy efficiency improvement efforts are applied. In practice, many factors limit the mitigation potential of a structural change: high costs, inavailability of technology and capital, and other resource constraints. For example, competing land uses between agriculture and "energy plantations" can limit the global mitigation potential of biomass.

61. One of the most systematic analyses of the long-term potentials of renewable and nuclear energy was carried out for the World Energy Council's 1995 Congress in Tokyo. A range of demand scenarios was explored with respect to alternative energy supply options. The study also considered international trade, availability and cost of technology, and other possible constraints. It was determined that the realization of the long-term mitigation potential of the options given would require near-term concerted research and development efforts. Technology demonstrations in initial niche markets to facilitate technological learning and cost reductions would be required so that the options become competitive with fossil fuels, particularly in the case of renewables and biomass. In the case of nuclear, acceptable responses need to be found to concerns about safety, waste disposal and proliferation. Hence, structural change would also be a more effective option if it were combined with vigorous energy efficiency improvement efforts.

D. Control of large point sources

62. The control of large point sources focuses primarily on reducing the emissions from power plants and large energy conversion facilities. The potential of this option is substantial. Possible control measures include scrubbers for carbon dioxide removal, applicable mostly to large fossil power plants, and some industrial processes. In most cases the technological feasibility of emission control has been demonstrated, although costs are still prohibitive in many cases.

63. The stabilization of atmospheric methane concentrations would require a reduction of current global anthropogenic emissions of 5 per cent. Such a reduction would equal about a quarter of the methane released by the energy sector. Current estimates indicate that the methane emission reduction potential at negative or low costs amounts to 10 per cent of anthropogenic emissions. The largest reduction potentials are in waste management and agriculture. In contrast, carbon dioxide scrubbing from flue gases is still prohibitive economically as a large-scale mitigation strategy. The feasibility of scrubbing and subsequent disposal of carbon dioxide still remains to be demonstrated on a large scale.

64. In addition, the problem of storing gigantic quantities of sequestered carbon dioxide for potentially thousands of years remains unresolved. Potential carbon dioxide utilization, disposal, and storage options include enhanced oil recovery, storage in depleted natural gas fields and other underground reservoirs, chemical feedstocks and other basic material, and finally disposal in the deep ocean. All of the options involve unresolved issues of possible long-term leakages, often unknown disposal costs, and perhaps most importantly, as yet unknown environmental impacts.

E. Enhancement of natural sinks

65. The enhancement of sinks is limited as a mitigation option to those greenhouse gases that are absorbed by natural sinks, such as carbon dioxide. Large amounts of carbon dioxide are continuously removed from the atmosphere through natural processes such as photosynthesis, the weathering of rocks, and absorption by the oceans. However, the rising concentration of greenhouse gases indicates that, due to anthropogenic activities, emissions have exceeded the absorptive capacity of the sinks. The enhancement of sinks can be achieved by a variety of measures, including so-called "geo-engineering" options such as deep ocean storage, weathering of rocks, and "iron-fertilization" of ocean plankton productivity. It is not known whether these options are feasible or whether they are associated with other significant environmental impacts. The most important option is the preservation and enhancement of the terrestrial carbon sink. Since vegetation is the largest sink, absorbing carbon dioxide by photosynthesis, the obvious measure is to halt global deforestation and enhance the growth of vegetation.

66. Estimates of carbon releases through land-use changes during the 1980s, including deforestation, indicate a net annual flux of carbon to the atmosphere of between 0.6 and 2.8 GtC. This compares to about 6 GtC from fossil-energy-related emissions. In addition to carbon dioxide emissions, deforestation and its associated biomass burning release other gases with a direct or indirect greenhouse effect - notably methane, nitrous oxides, and carbon monoxide.

67. Illustrative scenarios indicate that, in the absence of policy measures, deforestation rates could significantly increase future greenhouse gas emissions. Annual carbon dioxide emissions in the range of 3-5 GtC during the next century, could lead to an eventual destruction of the majority of the world's forests, including practical extinction in the tropical regions. In a worst-case scenario, up to 340 GtC might be released into the atmosphere over

the next century. In comparison, the current atmospheric carbon is about 760 GtC. By contrast, between 100 and 150 GtC could be sequestered from the atmosphere over the same time period through a dedicated global afforestation programme. However, afforestation costs can vary significantly between regions, in some cases by up to a factor of 30. It would have a significant impact on world timber markets. Regionally, different strategies must, therefore, be found to balance the impacts of a global carbon sequestration programme. From the perspective of the protection of the atmosphere and the carbon cycle, slowing down and eventually halting deforestation appears a more immediate priority for the enhancement of sinks.

F. Adaptation measures

68. The adaptation options comprise a large number of specific, preventive measures to enable people and natural ecosystems to adapt to possible climate change. This option could be employed in conjunction with mitigation measures or as a last resort in the case of unavoidable and significant climate change. Adaptation measures are not meant to protect the atmosphere but rather to minimize the adverse effects of possible environmental change due to human interference with the climate system. They are related to the inertia of the climate system, including the cumulative nature of anthropogenic emissions; the long lead times required between the political negotiation process, policy actions and the resulting reductions in emissions; and the significant time lags between stabilization of atmospheric concentrations and eventual climate stabilization. All told, even in the most ambitious policy scenarios some climate change appears inevitable as a legacy of the past, current and medium-term reliance on fossil fuels and the long response time of the climate system.

69. People and most ecosystems have a natural capacity to adapt to changes in climate. For natural ecosystems, adaptation to environmental change occurs naturally, albeit at very slow rates. Therefore, perhaps more important than absolute changes in climate are the rates by which climate change occurs. The possibilities of human intervention to facilitate or to speed up natural adaptation can be considered limited, apart from some generic measures such as the preservation of vegetation migration corridors. This is the principal reason why recent climate impact research identifies natural ecosystems as the most vulnerable to man-induced climate changes.

70. The adaptation potential of socio-economic systems is practically unlimited within the range of environmental and climate change anticipated over the next century. After all, human civilization exists under a much wider variation of climate regimes than projected by even the most drastic future climate change scenario. However, adaptation requires the availability of sufficient resources, appropriate research and development, better information and management practices, and know-how and time. It would entail potentially significant changes in practices, such as different agricultural crops or air and sea routes. Finally, some adaptation might entail considerable costs, such as the protection of low-lying coastal areas from a sealevel rise, relocation of infrastructure, and the construction of large enclosed areas for human protection.

VI. SPECIAL CIRCUMSTANCES IN DIFFERENT REGIONS

71. There are large disparities among different regions and countries in the capacity to mitigate and adapt to environmental changes caused by energy production and use. Despite significant differences among individual countries, this section attempts to summarize some specifics for each of three regional groupings in terms of the impact of global environmental change and the challenges for sustainable energy development.

72. Most of the countries in the OECD region are characterized by mature and highly developed economies, with high levels of income, energy consumption and energy-related greenhouse gas emissions. They share the greatest responsibility for the historical and current patterns of energy use and greenhouse gas emissions. They also have the greatest near-to-medium-term emission reduction potentials, the highest financial and technological mitigation and adaptation capabilities, and generally also the lowest vulnerability to environmental impacts.

73. Although highly industrialized, the economics in transition are characterized by a number of unique features. The transition process is disruptive and is taking longer than initially anticipated. Between 1990 and 1994, the combined economic output of the economies in transition fell by some 40 per cent. As a consequence, primary energy demand fell by some 25 per cent over the same period and energy-related carbon dioxide emissions, by some 30 per cent. These countries are thus probably well below any current or near-term commitments for stabilization of emissions, as formulated in the Framework Convention on Climate Change. Additionally, urgent social and economic priorities and severe capital constraints lead to low policy priority for any specific and additional mitigation or adaptation measures. At the same time, the process of economic restructuring opens further opportunities for efficiency improvements and structural changes in the energy sector.

74. It is estimated that the possible impact of climate change in the region would not be completely adverse. However, significant adverse impacts are anticipated for most of the natural ecosystems not managed by man - in particular, for boreal forests. There could also be some release of methane from permafrost areas, mainly in tundra soils and in the form of methane clathrates, which could have a significant additional warming impact because of the large quantities of methane captured in permafrost areas and methane's high radiative nature.

75. Developing countries face a triple challenge. First, their historical and current contribution to energy-related global environmental stress is low but is expected to increase in the future. Their share of energy-related carbon dioxide emissions is projected to surpass the 50 per cent mark between the years 2035 and 2045 and reach between 64 and 71 per cent by the end of the twenty-first century.

76. The second challenge deals with the much higher vulnerability of developing countries to possible climate change. There is broad agreement in various studies that in developing countries climate change accounts for a significantly higher proportion of damage to economic activities than in industrialized ones.

Developing countries also rely more on climate-sensitive activities such as agriculture. The impact of climate change is expected to be greater in developing countries due to multiple environmental and other stresses, including poverty, population growth, pollution, desertification, industrial and infrastructural development etc.

77. The third challenge relates to limited adaptation possibilities. Low national incomes result in low research and development budgets, severe capital scarcities and limited institutional capacities to deal with climate change.

VII. POLICY OPTIONS FOR CONTROLLING ANTHROPOGENIC IMPACTS

78. This section focuses on non-technical barriers and incentives for the protection of the atmosphere in the form of policy instruments, including market, regulatory and institutional measures. It is unlikely that any policy instrument would be justified or implemented solely in response to an individual environmental challenge. Clearly, policy instruments need first to be linked to local and regional development priorities such as the improvement of energy services or the improvement of local air quality. Some instruments require monitoring in order to ensure compliance.

A. Policies for sustainable energy development

79. Certain policy instrument measures raise both public and private awareness and help to reduce the significant scientific and policy uncertainties involved in long-term sustainable development and environmental issues. Research, both domestic and through international cooperation, can help to increase knowledge. Public awareness is critical to the promotion of a favourable social context and acceptance of the implementation of the numerous measures necessary in moving societies onto environmentally sustainable development path. No single mitigation option is likely to become the unique and universally adopted solution if drastic reductions of emissions from industrial, energy, and consumption activities are required. All options must be evaluated in their different regional, national or sectoral contexts and on the basis of full life-cycle analyses. The combination of several mitigation options along improved and new technology chains, plus associated synergies, will be needed in order to achieve substantial reductions in emissions. Considerable benefits are attached to options that tackle greenhouse gas emissions and also mitigate other adverse local and regional environmental problems. This point clearly implies a holistic approach to environmental problems and encompasses local and regional as well as potential global concerns.

80. No single policy measure or instrument will be sufficient for the timely development, adoption and diffusion of mitigation options. Special consideration must be given to policies that foster the adoption of mitigation technologies that enhance economic development without undermining global environmental sustainability. Policy instruments that make possible increasing supplies of high quality energy services and growth of per capita income and living standards should receive the highest priority in developing countries.

B. Policies for energy efficiency and decarbonization

81. High priority must be given to policy instruments that promote efficiency improvements. Such improvements, even using existing plant and equipment, can be achieved relatively quickly. The adoption of the currently best available technologies and practices can achieve substantial results. Efficiency improvements are particularly attractive as a target for policy instruments. They generate multiple benefits: lower resource consumption, reduced environmental impacts, and lower system costs.

82. The decarbonization of the energy system also promises multiple benefits. Decarbonization involves shifts to low-carbon and carbon-free energy sources and carriers. It is calculated as the ratio of average carbon emissions per unit of primary energy. The ratio decreases as fuels with high carbon content, such as coal, are replaced by those with lower carbon content or by carbon-free energy sources such as many renewables and nuclear energy. At the global level, decarbonization of energy occurs at a slow rate of about 0.3 per cent per year. This falls short by about 1.9 per cent of what would be required to offset the effects of the long-term, global growth in primary energy consumption, of about 2.2 per cent per year.

C. Market and non-market instruments

83. Market instruments include taxes, fees, tax exemptions, subsidies (including accelerated depreciation provisions), tradeable permits, the "polluter pays" principle and the internalization of environmental externalities. Non-market instruments include information, advertisements, education, standards, and legal and institutional regulations, bans and controls. Because of the huge number of economic agents involved and the difficulty of developing equitable incentives, such non-market instruments as building codes, vehicle standards, and stack emission regulations have been successfully used in many countries. Most market and non-market instruments work in both directions, removing or establishing barriers, or promoting or hampering progress. In the short run, the most promising area of the application of these instruments is the energy end-use sectors.

84. Recently, a hybrid of non-market and market of policy instruments has gained approval. Integrated resource planning (IRP) and demand-side management (DSM) are instruments imposed on utilities by regulatory institutions with the objective of shifting the focus from selling, for example, kWhs to selling energy services. DSM and IRP enhance the prospect for the development of combined heat and power (CHP) and district heat energy systems, increasing efficiency.

85. New institutional arrangements need to be introduced at the global level. Instruments for the promotion of sustainable development and for a major reduction in adverse environmental impacts will have to reach beyond voluntary compliance or reliance upon market forces alone. Implementing such schemes still requires careful negotiation.

86. The issue here is not so much one of market failure (wrong or misleading market signals) as of market exclusion. In numerous cases, important factors such as externalities have been excluded from any consideration in the market place.

87. Establishing special eco-zones might help to catalyse and accelerate sustainable development and the promotion of environmentally friendly technologies. Policy should support the creation of fertile socio-economic conditions. Likewise, broad market instruments are required to create an environment conducive to accelerated innovation and research and development.

D. Regional and national instruments

88. Policy instruments need to account for regional differences in the levels of human development and the resulting social and development imperatives, levels of resource endowment, and existing economic and technological structures. Instruments in regions with large hydro, wind, biomass or natural gas resources will be different from those in regions with small energy resource endowments. Alternatively, if deep ocean carbon dioxide disposal turns out to be environmentally acceptable, it is primarily of interest to certain coastal regions. Likewise, the option of carbon dioxide reinjection into depleted gas fields is only feasible in gas-producing regions.

89. Until the 1980s, regulation was the dominant environmental policy instrument at the national and regional levels. Recently, economic and market-oriented approaches have gained momentum. The application of market instruments at the macroeconomic level is intended to establish undistorted pricing mechanisms and competitiveness. In the energy sector alone, removal of distortionary fuel price subsidies is estimated to lead to substantial efficiency gains of up to 18 per cent of emissions. Many of these measures may also be needed to establish a level playing field.

E. Adequate financing

90. Neither the establishment of level playing fields nor temporary protection can overcome one major economic barrier, especially in the developing countries: namely, the chronic lack of capital. Even if a project has lower life-cycle costs and emissions but higher upfront capital requirements compared with its alternatives, it simply may not attract the necessary financing. In addition, energy and environmental measures compete for limited capital with many other development needs.

91. Even in the industrialized countries, where financing for capital-intensive projects is easier to obtain, there are major barriers to efficiency improvements and energy-sector restructuring and decarbonization at the national level. Often, higher returns can be obtained in areas other than the energy sector. The promotion of flexible, small-scale but mass-produced supply and conversion plants and equipment would help resolve some of the financing difficulties by reducing the risk, uncertainty, and up-front capital requirements.

F. Enhancing knowledge and skills

92. The uneven quality of general technology-related knowledge, experience and skills among regions and countries is a special problem. The know-how and know-why of developing countries on the development, import and adoption of new technologies often lags behind that of developed countries. Much of the information about mitigation options and implementation instruments is tailored to the needs and situations of the developed countries and thus is of limited use in the developing countries. There is need for reliable, impartial information on available technologies, including detailed descriptions; evaluations and technology assessments of how different options fit into diverse local situations are also needed. Hence, local capacity-building is essential.

93. The appropriateness of a given technology is an issue that must be specifically addressed. The industrialized countries need to provide for initial niche markets for new environmentally benign technologies in order for learning-curve effects and associated cost reductions to be exploited to the maximum before technologies are transferred to the developing countries. Existing international financial instruments for economic development are seriously out of tune with the need for innovation in the developing countries. Here, policy should encourage and support indigenous innovation and, as noted, enhanced local capabilities.

G. Sector-specific and technology-specific policy instruments

94. Policy instruments affecting the entire energy system include emission and energy taxation and regulatory provisions and standards. With the exception of fossil-fuelled electricity generation, the energy supply sector accounts for a smaller share of total energy-related greenhouse gas emissions than the energy end-use sectors. Therefore, carbon taxes levied at the point of emission would be collected primarily at the level of end-use and thus only indirectly affect the non-electric energy supply sector. An important generic aspect of regulatory measures is that they must restrict themselves to establishing more comprehensive costing principles by internalizing externalities and focus on performance and environmental standards rather than prescribing particular technologies.

95. Technology-specific instruments are very heterogeneous. They involve the promotion and development of individual technologies and their combinations into entire technology chains. The most important instruments of this type entail the removal of non-technical barriers to the innovation and adoption of new technologies and the creation of new ways of attracting development and diffusion.

96. Manuals, operating procedures and programmes are all an integral part of enhancing local skills and know-how. Skills and know-how in turn have to be acquired through formal education, training programmes and learning-by-doing. The human embodiment of technological knowledge is very important. Not only does it determine the internal capabilities for acquiring economic and social benefit from technologies; it also determines the capacity for further innovation and the adaptation of new technologies and practices. Capacity-

building and the development of human resources should be a high priority in any technology development and transfer programme, especially at the technology-specific level.

97. Another critical aspect is the transfer of technology and know-how from the laboratory and development stage to commercialization and subsequent diffusion. Relevant policy instruments include tax exemptions, subsidies with sunset clauses, rewards for technical excellence, end-user subsidies, promotion of integrated resource planning, and, where necessary, temporary protective measures. More importantly, the policy instruments should remove barriers to innovation such as protective subsidies for mature technologies and other market imperfections. Research and development policy should make earmarked and stable funding available for the development of technologies with long lead times. This precondition is of particular importance when the development of a whole set of new technologies is involved.

98. In the case of transition to completely new production and energy systems and technologies - sometimes called technological leap-frogging - it is important to take account of additional social costs for new infrastructure and supporting systems. A potential barrier might be the need to maintain both the old and the new systems during the transition period, leading to additional social costs and perhaps also unsatisfactory services. It is, therefore, important for the Government or some appropriate public body to promote the new systems and remove the hidden barriers until the systems are commercially viable.

99. Once a new technology is commercially viable, a new set of instruments is required to promote flexibility and cost reductions along the learning curve. In the case of modular and flexible technologies, cost reductions through learning-by-doing and learning-by-using can indeed be significant. In other cases, such as in the production of large amounts of biomass, the learning-curve effects could be more limited.

100. New problems, however, may emerge with increasing scales of production. Examples in energy supply are particularly numerous. Each generation of technology has a tendency to solve old problems and yet create new ones. Exceptional care will have to be taken if the policy instruments introduced for bettering the human condition and, at the same time, protecting the environment are to avoid creating a new round of problems and concerns.

Notes

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